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A Novel Plugin-Based Navigation Architecture for Multi-Brand, Multi-Screen Automotive Systems

Ronak Indrasinh Kosamia
rkosamia0676@ucumberlands.edu
0009-0004-4997-4225

Abstract— **In the rapidly evolving landscape of automotive infotainment, providing a robust, modular, and easily extensible architecture is paramount. This article presents a** plugin manager approach **for multi-brand, multi-screen navigation—aimed at automotive software built on top of Android and its Jetpack (including Compose) toolchain. As automotive OEMs increasingly demand brand-specific user experiences, developers often struggle with proliferating "if-else" conditionals, duplicated code, and tangled navigation logic. Traditional solutions, such as static route-based frameworks or theming engines, tend to buckle under the complexity of dynamic brand overrides. Meanwhile, adopting monolithic plugin architectures like OSGi or Eclipse RCP can be excessive and poorly tailored to Android's modern ecosystem. To address these challenges, we propose a** centralized plugin manager **that orchestrates brand-specific screens via discreet plugin modules. Each plugin encapsulates the unique UI and navigation flow required by a given brand, whether it's Volkswagen, Audi, or newer entrants to the market. At runtime, the plugin manager intercepts navigation requests, identifies the appropriate brand, and dynamically dispatches the user to the correct composable screen. This architecture not only curtails code duplication but also simplifies the on-ramp for new brand introductions: engineers simply drop-in new plugin classes—optionally annotated for automated registration using Kotlin Symbol Processing—without editing extensive branching logic. Our approach draws inspiration from well-known software patterns like Factory Pattern for the creation and retrieval of brand-specific plugin instances, Strategy Pattern for encapsulating brand-driven behaviors under a uniform BasePlugin interface and Annotation-Driven Patterns (e.g., KSP) for compile-time discovery and streamlined registration of these plugins. We also compare the plugin manager solution to alternative navigation techniques like Multi-module Gradle projects that manually swap resources per brand, Reflection-based override approaches prone to runtime overhead and poor type safety, and and Pure theming solutions that lack the flexibility to alter entire UI flows. The plugin manager approach offers a cleaner, more scalable middle ground—particularly relevant to the 90% of automotive stacks running on Android, where Jetpack Compose and Kotlin are increasingly becoming the de facto standards for creating intuitive, high-performance in-vehicle experiences. In short, this article offers actionable guidance for software architects and developers wrestling with the demands of multi-brand automotive infotainment. By marrying proven design patterns with Android's latest technologies, the plugin manager framework facilitates rapid expansion, reduces maintenance overhead, and empowers OEMs to elevate brand identity without sacrificing software maintainability. Through prototypes and real-world scenarios, we illustrate how this architecture effectively integrates into large-scale automotive programs, aligning with broader trends in modular software design and responding to the complexities of an ever-more diversified mobility marketplace.**

Keywords—automotive OEMs, OSGi, Eclipse RCP, KSP, Annotation-Driven Patterns, Jetpack compose, Factory and Strategy patterns, Reflection Override, Plugins Manager.

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I. Introduction

Automotive infotainment systems are evolving at breakneck speed. With new brands emerging, alliances shifting, and established OEMs continuously rebranding to keep up with market demands, developers find themselves in an unrelenting cycle of adaptation. If it's not an OEM wanting a sleek, minimalistic home screen for a premium model, it's another demanding a more playful, animated interface to lure a younger demographic. This reality creates a complex tapestry of code that, if not carefully managed, can become as confusing as trying to follow a vintage road map in the dark.

A. Why MultiBrand Navigation is So Challenging

In most modern vehicles, the underlying operating system is Android—along with a heavy reliance on Jetpack libraries, including Compose for UI[14]. On paper, Jetpack Compose's declarative structure is supposed to "simplify" UI creation but throw in five or six brands that each need their own spin on the layout (not just a new color palette), and you can quickly find yourself buried under conditionals and redundant code blocks. Traditional navigation techniques (like static routes, theming engines, or submodules for each brand) can become unwieldy when you're dealing with 30+ screens across multiple vehicle lines.

B. Common Approaches -and Their Pitfalls

1) Submodule per Brand: Many teams try to silo brand-specific code into distinct Gradle modules, each containing a full suite of screens. While this can work for a small set of brands, it doesn't scale nicely. Over time, identical or near-identical features get duplicated in each module, ballooning the codebase.

In this approach, the project is split into multiple Gradle submodules (or even separate repositories) such that each module contains the UI, logic, and resources for a single brand. For instance, you might have:

- brand-volkswagen/
- brand-audi/
- brand-skoda/
- brand-gmc/
- brand-cadilac/

Each module includes everything from UI layouts to data handling code that is specific to that brand.

Why Devs try it:

- It feels "clean" at first: each brand is neatly cordoned off, and you don't have messy $if - else$ statements scattered throughout the shared code

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- From an organizational standpoint, it's easy to onboard a brand-specific team that manages just that module.

Where it falls short:

- Duplication of Shared Logic: If multiple brands share, say, 80% of the same logic or similar layouts with only slight differences, you'll find yourself duplicating entire code chunks in each module. Over time, keeping these duplicates in sync becomes a maintenance nightmare.
- Dependency Entanglement: Often, brand modules still rely on "core" modules for data or navigation frameworks. Maintaining the proper dependencies can get messy. One small change in the core might break multiple brand modules, requiring repetitive updates.
- Scalability Issues: Imagine adding 5, 10, or 20 more brands. You multiply the overhead of having to tweak separate modules for each small fix or feature. Build times can also balloon because each module has to be compiled in context.

2) Theming Alone: We often see theming engines used to swap out colors, icons, or fonts dynamically. While theming is useful for subtle style differences, it does nothing for major UI layout variations or entirely different user flows. Think of it like using different wallpaper in every room of a house—when you need a different floor plan, wallpaper doesn't help. Android theming allows you to define color palettes, typography, shape appearance, and other style-related items. You can programmatically switch themes based on conditions—like detecting the brand at runtime.

- Why developers prefer it:

- Low Barrier to Entry: Changing a color or a font is straightforward. For minor brand variations, theming can solve the quick-win "skinning" scenario.
- Android-Supported Mechanism: Theming is well-documented, fits naturally with Jetpack Compose's Material/Material 3 layers, and integrates smoothly with other system-level theming features (dark mode, etc.).

Where it falls short:

- Superficial Differences Only: Theming is not designed to accommodate drastically different UI layouts, navigation flows, or specialized brand logic. If Brand A wants a multi-step onboarding flow while Brand B uses a single screen, theming alone can't handle that.
- Overuse of Theme Attributes: Even if you try to push theming further by encoding layout differences as theme-driven booleans or dimensional resources, you quickly end up with cryptic theme keys. This can also complicate maintenance when "themes" start dictating core flow logic rather than just visuals.
- Limited Extensibility: Adding a brand that wants a radically different design layout or feature set often requires new composables or code, anyway—thus defeating the convenience the theming approach was supposed to provide.

3) Reflection Based Override: Some advanced teams experiment with reflection to dynamically load brand-specific components at runtime. That can work but introduces new headaches in terms of performance, type safety, and maintainability—especially if you're aiming to keep your Kotlin code robust and your CI pipeline stable. With reflection, you dynamically load classes at runtime based on strings or configuration values (e.g., "If brand is X, reflectively instantiate the class named com.example.XHomeScreen). This approach sometimes overlaps with advanced "plugin" ideas but is typically more ad hoc.

a) Runtime Flexibility: You can load brand-specific classes even if they're in a separate library or downloaded module, making it tempting for those who want "hot swapping" or to minimize compile-time dependencies.

b) Avoiding Hard-Coded References: Some teams want to reduce direct references to brand code in the main codebase, and reflection *seems* like a neat trick.

Why not to use it:

- Performance & Complexity: Reflection can be slow and has extra overhead. On Android, particularly in automotive contexts, you're dealing with constraints like limited CPU power or tight real-time requirements. Reflection can add measurable lag or complicate the debugging process.
- Type Safety & Maintainability: If you get the class name wrong or rename a class without updating your reflective references, you won't catch the error until runtime. That's not fun in an automotive environment where a production bug might have critical in-car ramifications.
- Difficult to Navigate & Evolve: Code reviews and static analysis become harder because there's no direct reference linking the brand logic to the main flow. Over time, the system can devolve into "String-based Spaghetti".

4) "HyBrid" Conditonals: This is the dreaded (and ironically most common) approach of scattering brand-based $if - else$ or $when$ statements around the code. It starts simple ("$if brand == 'AudiORGMCorFord' then show X$") but grows into an unmanageable web of logic. Eventually, you're flipping coins to decide which file even holds the condition that's messing up the user flow this time.

Why Devs try it:

- Immediate Gratification: Adding a new brand-based tweak is as easy as appending another condition. No major architectural changes needed
- Legacy Inertia: Many codebases start out supporting a single brand, and as more brands get added, conditionals pile up. Developers might never step back to re-architect.

Why it falls short:

- Nightmare Maintenance: As brand variations multiply, you end up with nested or conflicting logic that's impossible to track. Want to rename a brand? Good luck searching for all references.
- Code Duplication: It's common to copy entire composable functions or entire classes—one for

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each brand—just to change a few lines. This is a recipe for bugs and confusion.

- Hard to Scale: The moment you hit double-digit brand counts, the approach crumbles under its own weight. Code merges become painful, and each new brand addition escalates the problem.

C. *Enter the Plugin Manager*

Our central idea is the **Plugin Manager[]**—a specialized piece of infrastructure that shifts brand differences into discrete "plugin" units [18]. Instead of splitting code by brand modules or baking brand logic into every screen, you have:

- **One** shared interface ($BasePlugin$) that each brand's plugin must implement (Strategy/Factory pattern influences).
- A **Plugin Manager** that discovers and registers these brand-specific implementations—optionally using Kotlin Symbol Processing (KSP) or other annotation-based tooling.
- A **Dynamic Navigation** layer (e.g., a NavGraph in Compose) that consults the Plugin Manager for each route, retrieving the appropriate composable "screen" for a given brand and screen name.

The result? You keep your main codebase uncluttered, and brand-specific logic is neatly encapsulated within plugin classes (or modules). Think of it like an assembly line: the same core "factory" can produce multiple brand configurations, each plugin focusing on what's unique for that brand's UI or flow[12].

D. *How Existing Patterns Influence the Plugin Manager Approach*

1) Factory Pattern: The concept of a plugin manager aligns nicely with a factory approach, where you "ask" for a plugin instance based on a certain key ($brand + screenName$) and let the factory produce the correct object without exposing all the messy details to the calling code.
Role in the Plugin Manager:

- Brand-Screen Lookup: The plugin manager can store a mapping of (brand, screenName) → pluginClass behind the scenes. When the system requests a screen for "Audi, Home," the factory portion of the plugin manager returns the correct plugin instance for that brand.
- Reduce Hard-Coding: By centralizing creation logic, we eliminate brand-based "if-else" in the code that triggers plugin usage. We only need to maintain those brand-plugin mappings in one place.
- Easier to Add/Remove Brands: Since creation details are contained within the manager, you can add or remove brand-specific plugins without rewriting large swaths of code.

2) Strategy Pattern: Each plugin is a distinct "strategy" for rendering or handling a particular screen. The rest of the system just knows it can call $plugin.\ loadScreen(\ )$, trusting that the plugin has all the brand-specific logic.
Role in the Plugin Manager:

- Common Interface (BasePlugin): Each brand's plugin implements a standard interface (e.g., BasePlugin) with methods like $loadScreen(\ )$ or $handleUserAction(\ )$. This "strategy" concept ensures the rest of the app doesn't care how the brand's internal logic is structured.
- Interchangeable Brand Logic: You can swap out the plugin for "Volkswagen, Home" with "Audi, Home" OR "GMC, Home" with "Cadillac, Home" simply by updating the brand parameter. Both respond to the same function calls, just with different brand-specific behavior.
- **Cleaner Codebase:** By abstracting brand logic behind a shared interface, your core modules and navigation code remain blissfully ignorant of the underlying brand complexities.

3) Annotation Driven Registration: Borrowed from frameworks like Dagger or Koin, this optional enhancement uses compile-time checks to collect all classes marked with, say, $@BrandPlugin\ or\ @ScreenPlugin$. A generated registry ensures you don't have to manually remember "Did we register the new brand's Home screen plugin?" It's automated.
Role in the Plugin Manager:

- Compile-Time Automation: Instead of manually editing a list of brand-screen mappings every time you add a new plugin, the annotation processor does it for you. This is particularly useful when supporting multiple brands that each have dozens of unique screens.
- Reduce Human Error: Annotation-driven discovery ensures you don't forget to register a brand plugin or mismatch brand identifiers.
- Seamless Integration with Android: KSP integrates smoothly with Gradle builds, making it straightforward to incorporate annotation-based code generation in your existing Android pipeline.

4) Why This Combination Works Best in Automotive

- Complex Brand Landscape: Automotive OEMs can have multiple sub-brands (e.g., Volkswagen (VW), Audi (VW), Škoda (VW), GMC (GM), Chevy (GM) and more), each with nuanced product lines (sports editions, luxury models, etc.). A purely theming approach or reflection-based approach soon hits a wall. Factories, Strategies, and Annotations give a flexible, type-safe structure that scales with brand complexity[11].
- $Android\ +\ Compose$ Synergy: The plugin manager can serve up brand-specific composables as "strategies" that get dynamically injected into the NavGraph or other Compose structures. This avoids the overhead and confusion of reflection or hand-coded submodules for each brand.
- Modularity and Maintainability: By blending these patterns, we isolate each brand's code into self-contained plugins that remain discoverable, testable, and manageable over time. Whether you're adding a brand or updating an existing one, the changes are localized, preserving the health of your overall codebase

E. *Relelvance to Android and Jetpack Compose*

In the automotive sphere, Android is king (or at least a very powerful monarch), claiming around 90% of all new infotainment system deployments. Jetpack Compose is

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increasingly becoming the standard way to build these UIs, making it critical that we craft an architecture that meshes seamlessly with Compose's declarative nature. By pairing a plugin manager with Compose-based screens, developers can deliver brand-specific UIs without forking entire codebases[14] or rewriting core flows whenever a new brand or special edition model is introduced. It is worth noting that Compose's flexibility makes dynamic screen rendering smoother, as you can pass around composable lambdas with minimal overhead. This is perfect for a plugin approach—once you fetch the relevant plugin for *(brand, screenName),* you simply call $plugin.\ loadScreen(\ )$which returns the composable UI.

F. Roadmap for the Article

This Introduction covered the current pain points in multi-brand automotive software and outlined how a plugin manager architecture can simplify things. Next, we'll dive deeper into **Related Work**—looking at existing navigation patterns, plugin frameworks, and annotation processing approaches. We'll then detail the **Proposed Architecture**, including code snippets, class diagrams, and a discussion of advanced features like server-driven plugins. An **Evaluation** chapter will explore maintainability metrics, performance trade-offs, and real-world usage scenarios. Finally, we'll wrap up with a **Discussion** of limitations, potential pitfalls, and areas for future exploration.

II. Proposed Plugin-Based Navigation Architecture

A. Overview and Design Goals

Our proposed architecture addresses the **core pain points** of multi-brand automotive infotainment—brand overrides, code duplication, and maintainability—by introducing a **Plugin Manager** as the central orchestrator. The design centers around:

1) Encapsulation of Brand Differences:
Brand-specific logic (e.g., for Audi vs. Volkswagen, GMC vs Chevy) is moved into discrete plugin classes rather than spread out in "if-else" blocks or separate submodules.

2) Flexible UI/UX Composition:
We leverage **Jetpack Compose's** declarative nature, allowing each plugin to define its own composable UI. This approach fits neatly with the dynamic routing common in Android-based head units.

3) Annotation Driven Registration (Optional):
Tools like **Kotlin Symbol Processing (KSP)** can auto-discover and register plugins based on developer-defined annotations. This reduces boilerplate and risk of human error.

4) Minimal Centralized Touchpoints:
The rest of the application only interacts with a **BasePlugin** interface and a **PluginManager**, keeping brand logic isolated from the core modules.

Why it Matters in Automotive:

- OEMs often juggle multiple brands or model lines, each needing unique UI flows.
- Time-to-market pressures demand that developers quickly introduce new brands or revamp old ones without rewriting the entire codebase.
- Infotainment software must remain stable, with a minimal footprint, given resource constraints on in-vehicle hardware.

B. High level Architecture

1) Application and Main Code base: The central business logic, navigation graph setup, and high-level data layers. This layer remains largely agnostic of brand details.

2) Plugin Manager: A singleton or globally accessible component responsible for:

- Storing mappings of $(brand, screenName) \rightarrow plugin$
- Resolving these mappings at runtime when the system needs to display a particular screen.
- (Optionally) hooking into annotation-driven code to populate these mappings automatically.

3) Plugins (Brand specific OR Shared):

- Each plugin contains the composable UI and brand-specific logic for a particular screen
- Must implement a **BasePlugin** interface, which defines essential methods like $loadScreen(\ )$**.**
- For instance, $AudiHomePlugin : BasePlugin, VolkswagenSettingsPlugin : BasePlugin$, etc

4) Base Plugin: A standard interface (or abstract class) specifying the contract every plugin must fulfill. Typically includes UI-related methods, lifecycle callbacks, or event handling relevant to an infotainment system.

C. Core Components in Detail

1) Plugin Manager:

- **Role**: The heart of the architecture, acting as a registry and "factory" for brand-specific plugins.
- Implementation Notes: Typically, a Kotlin object or DI-managed singleton.
  Provides functions like:

$$registerPlugin\,\mathrm{c}\begin{matrix} brand: String, screenName: \\ String, plugin: BasePlugin \end{matrix}\mathrm{e}$$

And

$$getPlugin\,\mathrm{c}\begin{matrix} brand: String, screenName: \\ String, plugin: BasePlugin \end{matrix}\mathrm{e}$$

- Could maintain both a brand-specific map and a fallback "shared" map for screens that are identical across brands.

PluginManager is arguably the central player in this architecture—think of it as the "brain" that determines which brand-specific UI elements you see and when. Below is a more thorough explanation of its role and implementation considerations:

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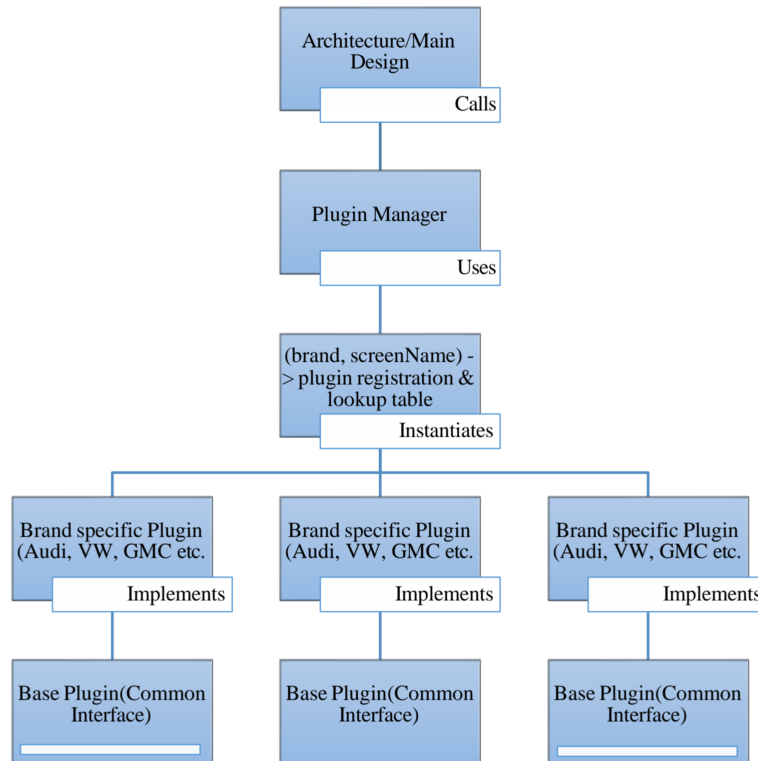

Code

```
object PluginManager {
  private val registry = mutableMapOf<Pair<String,String>,BasePlugin>()

  fun registerPlugin(brand: String, screenName: String, plugin: BasePlugin) {
    registry[brand to screenName] = plugin
  }

  fun getPlugin(brand: String, screenName: String): BasePlugin? {
    return registry[brand to screenName]
        ?: registry["SHARED" to screenName] // fallback
  }
}


interface BasePlugin {
  fun loadScreen(): @Composable () -> Unit
  // Potential for additional methods as needed
}


@ScreenPlugin(brand = "AUDI", screenName = "HOME")
class AudiHomePlugin : BasePlugin {
  override fun loadScreen() = @Composable {
    // Compose code with Audi color palette, layout, logic
    AudiHomeScreenUI()
  }
}
```

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2) BasePlugin Interface:

- **Role**: Defines the **Strategy** pattern. Each plugin (strategy) implements the same method signatures, ensuring the system calls them uniformly
- **Methods:**
  $funloadScreen(\quad): @Composable(\quad) \rightarrow Unit$
  - returns a composable function for the given brand's screen
- Optionally, you might include lifecycle or event-handler methods (e.g., $onScreenExit(\quad), handleVoiceCommand(\quad)$, etc.).

```
interface BasePlugin {
    fun loadScreen(): @Composable () -> Unit
}
```

3) Brand Specific Plugin Classes:

- **Role**: Concrete implementations that house brand-unique UI.
  Example:

```
  @ScreenPlugin(brand = AUDI, screenName = HOME)
class AudiHomePlugin : BasePlugin
{
        override fun loadScreen() = @Composable
        {
          // Compose code with color palette, layout, logic
          AudiHomeScreenUI()
        }
}
```

4) Annotation Driven Registration:

- **Role**: Automates the creation of a *PluginInitializer_Generated* class that registers each annotated plugin with *PluginManager*.
  Example:

```
  @ScreenPlugin(brand = AUDI, screenName = HOME)
class AudiHomePlugin : BasePlugin
{
        override fun loadScreen() = @Composable
        {
          // Compose code with color palette, layout, logic
          AudiHomeScreenUI()
        }
}

// Hypothetically generated code:
object PluginInitializer_Generated {
  fun registerAll() {
    PluginManager. registerPlugin("AUDI", "HOME",
       AudiHomePlugin())
    // ... for all discovered plugins
  }
}
```

D. Brand-Specific Vs. Shared Plugins

Why have shared plugins?

- Some screens (e.g., Settings, basic Info pages, system-level alerts) may look or behave identically across brands.
- Rather than duplicating them for each brand, we define a "SHARED" brand key or a default fallback. This ensures minimal duplication while still allowing brand overrides where necessary.

  Example:

- *SharedSettingsPlugin: BasePlugin* registered with brand = "SHARED", screenName = "SETTINGS".
- If a brand does not explicitly register a "SETTINGS" plugin, the system uses the shared plugin automatically.

E. Integration with Android Navigation (Jetpack Compose)

In most Android-based automotive systems, navigation is orchestrated by a **NavHost** or equivalent. Here's how the plugin manager solution meshes with Compose Navigation:

1) Compose Navigation Setup: You define a NavHost with your standard routes (e.g., "HOME", "SETTINGS", "PROFILE").

2) Runtime brand resolution: When the navigation logic detects a brand (e.g., from vehicle VIN decoding or user selection at startup), it passes that brand string to a composable screen function.

3) Plugin Invocation: Within the composable for each route, you retrieve the brand-specific plugin from *PluginManager.*

4) Compose Ui Render: The brand plugin returns the appropriate Compose UI via *loadScreen().* This is displayed in the existing NavHost seamlessly.

```
@Composable
fun MainNavGraph(selectedBrand: String) {
    NavHost(navController, startDestination = "HOME") {
        composable("HOME") {
            val plugin = PluginManager.getPlugin(selectedBrand, "HOME")
            plugin?.loadScreen()?.invoke()
              ?: DefaultHomeScreenUI()
        }
        // other routes...
    }
}
```

Fig 2. Plugin invocation

F. Key Advantage Over Existing Methods

1) Reduced Code Duplication: Brand logic is self-contained in plugin classes. Shared screens rely on a single plugin, drastically cutting down repeated code.

2) Ease of Adding/Modifying Brands: Developers can introduce or update brand logic by creating/updating a plugin class—no need to hunt down scattered if-else checks or theming resources.

3) Stronger Type Safety Compared to Reflection: By referencing classes directly (or via annotation-driven codegen), we avoid the pitfalls of string-based reflection. Build tools and IDEs can detect errors at compile time.

4) Better Scalability and Maintenance: New or experimental brands don't require re-architecture. The plugin

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manager model naturally extends to more brands and more screens.

5) Consistent Approach for UI Variation: Instead of mixing theming, reflection, and random checks, the plugin manager enforces a single, predictable pattern, making it easier for teams to collaborate.

G. Summary of Proposed Architecture

Our **Plugin-Based Navigation Architecture** unifies brand overrides in a structured, composable-friendly system. By combining:

- A **PluginManager** for brand-to-plugin mapping,
- A **BasePlugin** interface to enforce consistent APIs across brand implementations, and
- Optional **Annotation-Driven** registration to automate discovery,

we provide a **scalable**, **maintainable**, and **Android-aligned** solution for multi-brand automotive environments.

- Implementation Notes:

1) Singleton or DI-Managed Object: A common Kotlin pattern is to declare PluginManager as an object, which gives you a thread-safe Singleton with minimal boilerplate. Alternatively, you can integrate it with dependency injection frameworks like Dagger/Hilt or Koin, particularly if you want more granular control over lifecycle or scoped plugin instances. **Thread Safety**: Automotive head units might spawn multiple threads or coroutines (e.g., for voice recognition, sensor updates). If plugins are manipulated concurrently, you may need synchronization. (e.g., *synchronized blocks* or using concurrency-safe data structures like *ConcurrentHashMap).*

2) Registry Functions: Two essential methods usually suffice: *fun registerPlugin(brand: String, screenName: String, plugin: BasePlugin)* and *fun getPlugin(brand: String, screenName: String): BasePlugin?*. If you're using annotation processing (e.g., KSP), a generated initializer class can call registerPlugin for each discovered plugin and For a manual approach, developers might add registration calls in an *onCreate* or init block. This manual route is more error-prone but still viable for smaller projects.

3) Data Structures for Brand Mapping: A straightforward approach is to store everything in a *Map<Pair<String, String>, BasePlugin>,* where the key is (brand, screenName) and the value is the plugin instance. For fallback behavior, you could also keep a special "shared" map or a shared brand key ("SHARED" or "DEFAULT"). When *getPlugin* fails to find an exact match, it looks up the fallback.

```
private val registry = mutableMapOf<Pair<String, String>, BasePlugin>()
private val sharedRegistry = mutableMapOf<String, BasePlugin>()
```

Another layer might include versioning data or priority if your setup needs advanced plugin conflict resolution.

4) Handling Lifecycle and Cleanup: In some automotive scenarios, you might need to unload or disable plugins at certain times (e.g., memory constraints, updated brand packages, or new software releases). The *PluginManager* could maintain a reference count or a "state" for each plugin, allowing it to clean up resources when no longer needed. For instance, you might have a *unregisterPlugin(brand: String, screenName: String)* method, particularly if your system supports dynamic updates over-the-air.

5) Error Handling and Logging: If *getPlugin* returns null, you can either render an error screen or fallback to a safe default. In a vehicle context, having a graceful fallback is crucial—unexpected crashes can be both brand-damaging and unsafe. Logging is vital for diagnosing brand-related issues. The manager can log whenever a brand tries to register a screen that's already taken, or if two conflicting registrations occur.

6) Scalability Concerns: If you have dozens or even hundreds of brand-screen combos, lookups need to remain efficient. A hash map is typically sufficient for this scale. Additionally, consider memory usage: each plugin might hold references to resources. In extremely resource-constrained environments, you could instantiate plugins lazily rather than all at once.

In summary, the **PluginManager** is the linchpin of this entire approach—an elegant blend of a registry and factory pattern, ensuring that each (brand, screenName) combination leads to the right composable UI. By consolidating creation, lifecycle, and fallback logic, the manager lets you keep the rest of your infotainment app pleasantly free of brand-specific clutter.

III. Evaluation of Plugin-Based Navigation Architecture for Multi-Brand Automotive Software

1) Maintainability:

- Code Reuse and Reduced Duplication:
  A plugin-based navigation architecture greatly improves maintainability by eliminating repetitive code across brands. Instead of copying and tweaking the same screens for each automotive brand, common functionality resides in core modules, while brand-specific differences live in separate plugins [1]. This unified approach means that adding a new brand does not require cloning large sections of the codebase, thereby keeping the system cleaner and more consistent [2]. In practice, a single codebase with brand-centric plugins allows features to be easily reused across multiple OEMs, reducing both development effort and the risk of divergence [3].
- Simplified Structure:
  Plugins localize complexity. Each brand's custom screens or flows are encapsulated in its own plugin, loosely coupled to the application via well-defined interfaces [4]. This modular separation makes it easier to reason about the system—teams can work on, for example, a "FordPlugin" or "BMWPlugin" independently. This avoids scattering if statements or brand checks throughout the core logic [5]. The project structure thus remains more straightforward: the core navigation and shared components stay in

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one place, while each plugin manages a brand's unique aspects [6].

- Long-Term Manageability:
  Over time, this approach significantly eases long-term maintenance. Since brand-specific customizations are decoupled, changing one brand's requirements has minimal impact on others [15, 7]. Common bug fixes or feature enhancements in the core apply to all brands automatically, preserving consistency, while unique new features can be added to only one brand's plugin if needed [8]. This clean separation aligns with the open/closed principle: the system is open to extensions (new brand plugins) yet closed to sweeping alterations in the core for each new variant [9]. Moreover, plugin-based navigation can handle rebranding or UI refreshes gracefully by centralizing updates while isolating brand-specific designs [10].

2) *Performance Considerations*:

- Runtime Efficiency:
  A chief concern with modular architectures is the runtime cost of loading and using plugins. On modern Android systems (including automotive variants), there is negligible overhead until a plugin is actually referenced [1]. When packaged as dynamic feature modules, brand-specific code remains inactive until needed. If the system is configured so each device only loads its applicable brand plugin, the performance is nearly identical to that of a single-brand app [3].
- Memory Usage:
  Memory overhead is also minimized. Only the active brand plugin's classes and resources are loaded, while shared components remain in the core [2]. This is inherently more efficient than maintaining multiple brand forks or submodules in memory at once. If each vehicle build contains only the plugin for that brand, the approach becomes lean. Even when shipping multiple plugins together in one APK or AAB, memory usage is on par with any standard multi-module architecture [4].
- Dynamic Loading Overhead:
  When dynamic features are introduced at runtime, there is a one-time load cost [5]. If plugin registration relies on reflection, it can introduce an additional delay and type safety concerns; however, a well-structured plugin manager typically uses reflection just once (to discover or initialize plugins) and then relies on strongly typed interfaces [6]. Caching plugin references after initial load keeps repeated lookups efficient. Overall, steady-state performance remains on par with a monolithic solution.

3) *Scalability:*

- Adding New Brands:
  This plugin-based design excels when scaling to multiple brands. To onboard a new OEM, developers create or extend a plugin module that implements the required screens and flows [7]. No major refactoring of the existing code is necessary, reducing both risk and costs. In a real-world scenario where a supplier might support over a dozen OEMs, each with unique brand identities, this isolation proves invaluable [8].
- Adding New Screens/Features:
  Scalability also applies to feature growth. A new feature can be introduced as a plugin accessible to all brands or selectively to some, depending on requirements [2]. Android's modular navigation capabilities allow you to integrate separate navigation graphs at runtime, enabling a flexible yet consistent approach to bundling features [3]. Consequently, the overall system scales both in brand count and feature complexity, retaining clarity rather than devolving into unwieldy conditional checks.
- Resource and Configuration Scaling:
  One caveat is the overall number of modules. Each additional plugin introduces new build configurations and potential version mismatches [9]. However, robust Gradle build scripts and version catalogs can mitigate much of this overhead. Compared to approaches like theming or submodule-based duplication, plugin modules still yield a better outcome for large-scale brand expansions [10].

4) *Industry Relevance:*

- Alignment with Android Automotive Trends:
  The automotive sector is increasingly pivoting to Android for in-vehicle infotainment (IVI) platforms. Android Automotive OS is designed for OEM customization, allowing manufacturers to implement bespoke UIs and brand experiences on top of the same underlying system [1]. A plugin-based architecture empowers rapid brand differentiation without maintaining multiple code forks or complex preprocessor macros. By aligning with official Android guidance on modular applications, this approach meets OEM demands for agile customizations while keeping code quality high [2].
- Jetpack Compose & Kotlin Synergy:
  Jetpack Compose is now the recommended way to build UIs on Android, offering a declarative model that aligns perfectly with plugin-based solutions [3]. Compose screens are, in essence, Kotlin code, making them easily packaged in plugin modules. Additionally, Kotlin's modern language features (coroutines, extension functions, sealed classes) simplify the creation of robust plugin interfaces [4]. Given that many automotive projects are Kotlin-first, adopting a plugin-based approach dovetails nicely with industry-favored development practices [5].
- Modular Architecture and Best Practices:
  Across the Android ecosystem, Google increasingly advocates for modular app designs to improve build times, code organization, and dynamic feature deployment [6]. In automotive, where projects often have multiple layers (navigation, media, telematics, brand identity), the benefits multiply. This plugin-based method, which can be viewed as an evolution of dynamic feature modules, helps cut through the

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complexity, centralizes brand differences, and accelerates time-to-market for new OEM variants [7].

5) Comparision between Existing Approach:

In order to contextualize the plugin-based navigation system, we compare it against three common strategies used for multi-brand automotive apps: **theming-based**, **per-brand submodules**, and **reflection-based dynamic loading**. Each approach offers particular strengths and weaknesses depending on the project's size, brand variability, and expected lifecycle [1][2][3].

a) Discussion:

- **Plugin-Based Navigation:** Best for moderate-to-large projects needing frequent brand changes or additions [4]. It isolates brand logic effectively but requires up-front design of plugin interfaces.
- **Theming-Based Solutions:** Great if differences are purely cosmetic (color, typography). Falls short when entire screen flows differ [5].
- **Per-Brand Submodules:** Useful if each brand truly diverges in features, but duplications accumulate quickly [6].

TABLE I. COMPARING THE PLUGIN-BASED APPROACH WITH ALTERNATIVE SOLUTIONS

Approach	Methodology	Advantages	Trade-offs / Disadvantages
Plugin-Based Navigation (Proposed)	Use modular plugins for each brand's screens and flows. The core app defines an interface or extension points, and brand modules "plug in" to the navigation graph.	- **High maintainability**: No code duplication; shared logic remains in a single codebase.	- **Initial complexity**: Requires upfront design of plugin APIs.
		- **Scalable**: Each new brand is simply another plugin.	- **Performance overhead**: Possible if using reflection or dynamic loading.
		- **Loose coupling**: Minimizes brand checks scattered across the code.	- **Build overhead**: Multiple modules mean more config to manage.
		- **Runtime flexibility**: Dynamically load or select brand modules as needed.	
Theming-Based Solutions	Switch resources (colors, icons, layouts) at runtime or build time to achieve different UIs for each brand. Often used for minor cosmetic differences.	- **Simple** for purely aesthetic differences.	- **Limited scope**: Cannot handle complex brand logic or flows.
		- **No dynamic overhead**: The app has all resources pre-bundled.	- **Scalability issues** if many brands have major layout differences.
		- **Easy brand re-skins** if differences are minimal.	- **Testing overhead**: One codebase must accommodate all brand variations.
Submodules per Brand	Maintain separate Gradle modules (or entire forks) for each brand. Each brand's code extends or overrides a shared core library.	- **Isolation**: Each brand can evolve independently.	- **High code duplication**: Risk of repeating logic in every submodule.
		- **Easy for major brand divergences** in features.	- **Poor scalability**: Each new brand means a new module with repeated code.
			- **Maintenance burden**: Fixes or enhancements might be applied repeatedly across modules.
Reflection-Based Loading	Use reflection to dynamically locate and load brand-specific classes or resources. Often used when the core app has no compile-time reference to brand modules.	- **Runtime flexibility**: The brand plugin can be shipped or updated independently.	- **Performance overhead**: Reflection can slow app startup or navigation calls.
		- **Hard separation**: Core and brand are loosely coupled at compile time.	- **Type safety issues**: Errors only surface at runtime.
			- **Complex** to maintain and debug.

- **Reflection-Based Loading:** Offers excellent decoupling at runtime yet poses higher performance and maintenance risks [7].

By balancing these approaches, **plugin-based navigation** emerges as a strong choice for multi-brand automotive projects, especially when brand experiences differ beyond

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mere visual tweaks. It preserves modularity, keeps the core code clean, and fits nicely with modern Android tooling (Kotlin, Jetpack Compose) [8].

IV. Implementation and Case Study

As explained previously, a **PluginManager** is the key orchestrator in this architecture. Each brand-specific feature (or plugin) implements a shared *BasePlugin* interface and registers itself in one of two ways 1) Manual Registration and 2) Annotation Driven Registration.

A. *Overview of Approach*

1) Manual Registration: The developer explicitly calls *pluginManager.registerPlugin(brand,screenName,pluginIns-tance)* in a startup function or initialization code.

2) Annotation Driven Regisration: A **Kotlin Symbol Processor (KSP)** looks for classes annotated with *@ScreenPlugin(brand, screenName)* at compile time. The generated *autoRegisterPlugins(...)* function automatically wires all discovered plugins to the manager, sparing developers from repetitive registration chores. In automotive contexts where new screens emerge often (especially in navigational software), the annotation-driven approach reduces human error and streamlines large-scale brand additions.

B. *Small Climate App - Manual Registration Approach*

The first project was a **simple climate control application** for a single OEM screen override. Because only one screen needed a brand-specific tweak, using an annotation processor felt like overkill. Instead:

1) One plugin class was created, implementing BasePlugin.

2) A manual registerPlugin("GMC", "ClimateScreen", gmcClimatePluginInstance) call occurred during app initialization.

For Instance:

```
class ClimatePluginManager {
   private val plugins = mutableMapOf<String,
BasePlugin>()

   fun registerPlugin(brand: String, screenName: String,
plugin: BasePlugin) {
       plugins["$brand-$screenName"] = plugin
   }

   fun getPlugin(brand: String, screenName: String):
BasePlugin? {return plugins["$brand-$screenName"]}
}

// In your Application or DI setup:
val pluginManager = ClimatePluginManager().apply {
   registerPlugin(
       brand = "GMC",
       screenName = "ClimateScreen",
       plugin = GmcClimatePlugin()
   )
}
```

Key Observation:
With minimal brand variation, manual registration was entirely sufficient. Should the climate app expand to multiple screens or additional brands (like Cadillac), shifting to the annotation system would be straightforward.

C. *Navigation App - Annotation Driven Approach*

The second scenario—a **navigation map application**—required several screens.

- **Search Screen** (location search functionality)
- **Saved Destinations** (managing user-saved waypoints)
- **Route Guidance** (turn-by-turn directions, EV route planning)
- **Trip Options** (eco mode, fastest route, scenic route, etc.)
- **Detailed Display** (map overlays, location metadata)

Registering this many screens purely by hand would be cumbersome, so the annotation-based method proved ideal:

1) Annotate Each Plugin:

```
@ScreenPlugin(brand = "CADILLAC", screenName =
"SearchDisplay")
class CadillacSearchDisplayPlugin : BasePlugin {
   // ...
}
```

Here, *@ScreenPlugin* encodes the brand "*CADILLAC*" and the screen name "*SearchDisplay*."

2) Compile Time Code Generation: A custom ScreenPluginProcessor iterates through all *@ScreenPlugin* classes. It outputs a *PluginInitializer_Generated.kt* file with *autoRegisterPlugins(pluginManager),* which systematically registers all discovered plugins.

3) Plugin Manager and Base Plugin: The PluginManager in this navigation suite is similar to the climate version but handles multiple brand-screen combos. When the user selects a brand or the system detects an OEM configuration, the manager fetches the correct plugin at runtime:

```
val plugin = pluginManager.getPlugin(currentBrand,
                                      screen.name)
plugin.LoadScreen(/* parameters */)
```

4) NavHost Integration: By injecting pluginManager into a composable function (*e.g., YourAppNavGraph),* each route *(like "DetailedDisplay/{locationId}")* obtains its plugin at runtime. If *currentBrand* has no override, it can default to a "*SHARED*" plugin or throw an error.

Result:
This annotation-driven pipeline **eliminates** manual wiring across numerous screens. Adding or renaming brand plugins is frictionless—simply annotate a class and recompile.

D. *Directory and Package Structure:* Both projects maintain a similar top-level organization, yet handle brand logic separately.

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```
project-root
├ climateApp
|   └ GmcClimatePlugin.kt
|      └ ClimatePluginManager.kt
├ navigationApp
|   └ src
|      ├ main
|      |   └ java/com/...
|      |      ├ plugins/
|      |      └ annotations/
|      |         ├ ScreenPlugin.kt
|      |         ├ ScreenPluginProcessor.kt
|      |         └ ScreenPluginProcessorProvider.kt
|      └ ...
└ ...
```

- **climateApp** folder: Manual plugin approach for a single brand override (GMC).
- **navigationApp/plugins**: Houses multiple brand screen overrides (Cadillac, possibly GMC, or SHARED screens).
- **navigationApp/annotations**: Contains the annotation and KSP classes.

E. *Code Snippet Highlights:*

In the **navigation** app, the important logic is:

1) Annotation Declaration:

```
@Target(AnnotationTarget.CLASS)
@Retention(AnnotationRetention.SOURCE)
annotation class ScreenPlugin(
        val brand: String,
        val screenName: String
)
```

2) Symbol Processor:

```
class ScreenPluginProcessor : SymbolProcessor {
//Looks for classes annotated with
 // @ScreenPlugin,
        then generates registration code
}
```

3) Auto Generated Initializer:

```
fun autoRegisterPlugins(
    pluginManager: PluginManager) {

// Scans brand → screen
        → constructor, registering them
}
```

4) NavGraph Usage:

```
  val plugin = pluginManager.getPlugin(
              currentBrand, screen.name)
  plugin.LoadScreen(
    /* Compose parameters, etc.*/ )
```

F. *Lessions Learned*

1) Small Vs Large Apps:

- A tiny single-screen climate app didn't need annotation overhead.
- The multi-brand, multi-screen navigation scenario strongly benefited from auto-registration.

2) Fallback Logic:

- Many route flows can be SHARED across brands unless overridden. The architecture ensures brand fallback with minimal code duplication.

3) Jetpack Compose Integration:

- Passing *ViewModels* and UI state is straightforward since *LoadScreen* functions accept composable parameters.

4) KSP Advantage:

- Kotlin Symbol Processing provided faster compile times vs. legacy approaches and integrated smoothly with the Kotlin-based build system.

5) Testing and Validation:

- Automated tests involved verifying each plugin loaded properly for its brand while unregistered brand-screen combos defaulted as expected.
- The system's clarity made it simpler for QA teams to confirm brand-specific features were indeed isolated.

G. *Summary of Implementation and Case Study*

Two real-world automotive applications underscore the **scalability** and **modularity** of a plugin-based approach:

- **Climate Control (GMC)**: Only one brand override, registered manually in a short block of code.
- **Navigation App (Cadillac / Shared)**: Multiple screens, each annotated for compile-time discovery, freeing developers from constant "wire-up" tasks.

In both examples, a **PluginManager** handles brand routing and ensures the correct composable UI loads at runtime. The key distinction is **how** plugins are registered: small-scale or immediate use-cases thrive on manual calls, while a large, multi-brand architecture benefits from **annotation-based** auto-registration. This architecture aligns seamlessly with **Kotlin + Jetpack Compose** best practices, minimizing code repetition and enabling agile expansions for any future GM brand or screen.

V. DISCUSSION

A. *Strengths and Observations*

1) Modular Separation of Brand Logic: One of the most prominent advantages is the clean separation of brand-specific code into discrete plugins. Especially in an automotive setting—where new brands or model lines can appear frequently—this means developers can work on unique features (like a Cadillac-specific climate layout or GMC route-planning flow) without impacting shared modules. This often translates to lower risk of regressions and faster iteration, particularly when multiple teams work on different brand customizations concurrently[17].

2) Kotlin + Jetpack Compose Synergy: The approach slots neatly into **modern Android** ecosystems, leveraging

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Jetpack Compose's composable architecture to swap UI screens at runtime. Because each brand's UI is delivered as a composable, the plugin manager simply has to decide "which composable to show," which is far simpler than bridging multiple XML layouts or reflection-laden solutions. The technique also aligns with ongoing industry trends toward Kotlin-first development, making it **forward-compatible** with future Android changes.

3) Annotation-Driven Scalability: Projects with only a single or a handful of brand-specific screens may manage with manual plugin registration. But for **multi-brand, multi-screen** apps—like the navigation case study—annotation-driven registration proves valuable, preventing what might otherwise be a labyrinth of manual calls. The synergy with Kotlin Symbol Processing (KSP) ensures compile-time detection of any newly added plugin classes, centralizing code references in a generated file. This significantly **reduces human error** and code boilerplate when introducing new features or brands.

4) Runtime Flexibility: Even though we're not heavily leveraging dynamic feature modules in this paper, the plugin approach naturally lends itself to that realm. In principle, an automotive application can package (or download) brand plugins on demand, only loading them when needed. This idea aligns with the broader concept of "over-the-air (OTA) updates," where an OEM can deploy new brand experiences or UI enhancements without altering the entire system image[16].

5) Common Sense for Multi-Brand: In a domain where software reuse is crucial—car platforms can last for multiple model years—the plugin architecture ensures shared functionality remains in a central codebase. Instead of brand forks or flavor-based code duplication, features and logic are systematically re-applied to each brand via plugin overrides only where necessary.

B. Limitations and Potential Pitfalls

1) Build Complexity with Many Plugins: As the number of brand modules grows, the build system can become cumbersome to maintain. Managing dependencies, versions, and testing across a large plugin ecosystem requires robust DevOps practices (like Gradle version catalogs or a well-structured monorepo).

- Mitigation: Automated tooling integrated continuous integration (CI) pipelines, and thorough documentation can keep the overhead manageable.

2) Conflict Resolution: When two plugins attempt to override the same (brand, screenName) combination, the plugin manager must decide which plugin has priority. While this is often a moot point (since each brand override is unique), unexpected conflicts can arise if, for example, **multiple teams** develop brand-coded features that target the same screen.

- Mitigation: Strict rules for brand ownership or requiring a brand "namespace" help avoid collisions.

3) Initial Architecture Effort: Projects adopting the plugin-based approach must invest upfront in designing interfaces, setting up KSP annotation processors (if going that route), and teaching teams the plugin approach. This is not trivial, especially if the organization has historically relied on static theming or copy-and-paste brand forks.

- Mitigation: Provide thorough onboarding materials and code templates. The payoff comes in **long-term maintainability** and extensibility.

4) Testing Complexity: While the architecture localizes brand differences, QA/testing teams must still confirm correct brand behavior in each plugin. A brand having 10 screen overrides means 10 separate flows to test. If using a "SHARED" fallback, you also must ensure brand screens that do **not** override are indeed functioning as the fallback.

- Mitigation: Automated UI tests and snapshot testing can systematically validate each brand-screen combination.

5) Platform Constraints: Some automotive head units may limit reflective or dynamic class loading. Although the approach described here can minimize heavy reflection calls, it still relies on Kotlin's runtime (and possibly partial reflection for annotation-based solutions). OEMs with strict memory or CPU constraints might need to carefully evaluate whether they can afford the additional overhead at startup.

- Mitigation: If dynamic loading is not feasible, the system can still register plugins at build time in a monolithic fashion (the architecture remains valid; only the "dynamic" aspect might be scaled back).

C. Future Prospects

1) OTA-Driven Plugin Updates: As automotive systems become more connected, OEMs may want to push brand UI updates over the air. A plugin-based approach can facilitate this by packaging brand modules as separate artifacts, updating them independently from the main system. OEM branding can evolve mid-lifecycle, or new features can roll out to existing vehicles.

2) Deeper Integration with Microservices: In some advanced setups, individual vehicle features (navigation, media, climate control) might be tied to backend microservices[15]. A plugin-based system might coordinate with a microservice registry, discovering new "brand plugins" or custom features without a full software re-flash. This approach has parallels to micro-frontend designs in web ecosystems.

3) Granular Brand Overrides: Instead of brand-level overrides, future expansions might allow screen "partial overrides." For instance, a brand might override only the color scheme or a portion of the layout in a screen, leaving the rest shared. The plugin manager could orchestrate "plugin composition" so multiple overrides combine elegantly..

4) Cross-Platform Extension: While Kotlin and Jetpack Compose are native to Android, the concept could stretch to other environments (like **iOS** or embedded QML frameworks). Automotive suppliers often desire "one logic base" across cluster, head unit, and even companion apps. Although not trivial, a plugin-based pattern might eventually unify multi-brand logic across multiple OSes.

5) Advanced Conflict Resolution & Versioning: With enough brand variations, partial conflict resolution might become more sophisticated (e.g., "Cadillac rides on version 1.2 of a route plugin, but GMC uses version 2.0 with different

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data flows."). Maintaining multiple plugin versions concurrently would require a robust solution—like semantic versioning or pinned plugin configurations.

D. Concluding Remarks on Discussion

Overall, the plugin-based navigation system strikes a **pragmatic** balance between maintainability and flexibility. It offers a clear path for extending brand features without entangling every screen in conditional checks. The approach does, however, demand a well-organized repository and clarity in brand ownership—especially in large, distributed teams. Future expansions in areas like OTA updates, partial overrides, and cross-platform synergy could further cement plugin-based architectures as a mainstay in **automotive software**.

VI. Conclusion

In summary, **plugin-based navigation architectures** offer a robust path to long-term maintainability in modern automotive software, where code complexity can reach hundreds of millions of lines [1]. By decoupling brand-specific screens into discrete modules, developers reduce duplication and avoid bloated conditional logic, thereby **streamlining maintenance** and localizing complexities [2]. This modularity also aligns well with **Kotlin + Jetpack Compose**—the recommended stack for modern Android-based in-vehicle infotainment—enabling seamless integration between brand overrides and the underlying UI system [4].

Real-world adoption of similar modular principles underscores the practicality of this approach. Contemporary automotive frameworks often emphasize service-oriented or plugin-friendly designs, reflecting a broader industry trend toward **component-based** and **extensible** architectures [3], [5]. Whether in the context of multi-brand HMIs or large-scale dynamic feature loading, the ability to isolate distinct functionalities as plugins delivers tangible benefits in **collaborative development**, **partial updates**, and **parallel brand feature rollouts** [7], [8]. Moreover, repeated case studies suggest that well-defined plugin APIs mitigate technical debt by preventing codebase forks and brand-specific branches from diverging uncontrollably [9].

In addition, a plugin-based navigation system naturally dovetails with emerging **microservices** paradigms in connected vehicles. Each plugin can be thought of as a self-contained service—communicating through a clearly specified interface—making it straightforward to integrate with backend microservices for data (e.g., traffic, charging stations) and supporting over-the-air (OTA) updates [6], [10]. As OEMs shift toward continuous software delivery, the ability to deploy or replace a plugin without redeploying the entire stack can shorten release cycles and reduce on-vehicle downtime. This approach also opens the door to **function-on-demand** business models, where drivers can opt into new brand experiences or screen features dynamically.

Ultimately, the plugin-based method strikes a **practical balance** between flexibility and maintainability[17]. While an initial investment is required to set up the plugin manager, define interfaces, and (optionally) configure annotation processors, the payoff comes in **agility**: new brands, screens, or microservices can be integrated with minimal disruption to the existing code. As the automotive sector continues to evolve—embracing software-defined vehicles, cross-brand collaborations, and connected ecosystems—this architecture provides a scalable foundation. It not only enables efficient **multi-brand** customizations but also positions organizations to adapt rapidly to future demands in user experience, regulatory changes, and emerging technologies.

In essence, the **plugin-based navigation architecture** is an invaluable strategy for engineering teams seeking to consolidate brand variations, reduce technical debt, and capitalize on microservices-driven opportunities. Through modular design, clear interfaces, and a Kotlin + Compose synergy, it anticipates the **next generation** of in-vehicle infotainment and beyond—where software evolves constantly and must be both secure and maintainable over extended product lifecycles [2], [5], [10] [16].

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